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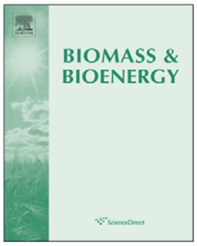

Wood fuel use in the traditional cooking stoves in the rural floodplain areas of Bangladesh: A socio-environmental perspective

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ABSTRACT

A study was conducted, using a multistage simple random sampling design, to determine the structural characteristics of the traditional cooking stoves, amount of wood fuel consumed in the rural floodplain areas in Bangladesh, and also to figure out the socio-economic and environmental consequences of wood fuel usage in the traditional cooking stove. The study showed that family size, income, amount cooked and burning hours significantly affected the amount of wood fuel used per family per year. Taking into account different family sizes, the study observed that 4.24 tonne fuelwood were consumed per family per year. The study showed that 42% of families used only biomass fuel, 5% used liquefied petroleum gas (LPG) and 53% used kerosene along with biomass fuels. The main source of biomass fuel was homestead forests (40%). It has been figured out that the incomplete combustion of biomass in the traditional cooking stove poses severe epidemiological consequences to human health and contributes to global warming. The study also showed that 83% of the respondents would prefer improved cooking stoves over traditional cooking stoves.

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1. Introduction

In Bangladesh, about 76% of the population lives in the rural areas in 19.46 million households spread over 87,362 villages with an average family size of 4.9 per household [1]. The chief sources of energy used in Bangladesh are biomass fuel, natural gas, oil, coal and electricity. The people in the rural areas depend mainly on traditional fuels, namely wood and agricultural residues. Overall, trees and bamboo provide around 48% of the current domestic energy requirements, agricultural residues 36% and dung 13% [2]. In the rural areas in Bangladesh, foods are cooked in the traditional cooking stove where biomass fuels are mainly used as energy because of the unavailability of natural gas. It is assumed that large quantities of carbon dioxide (CO_2) are emitted from these stoves, but the emissions from this use of biomass are thought to be GHG neutral if the biomass fuel cycle relies on renewable harvesting [3]. Due to the increased population growth and repeated fragmentation of the village forests, the biomass fuel cycle in the rural floodplain areas of Bangladesh is probably unsustainable [4]. Rather, it leads to increased collection of fuel wood from village forests and consequent deforestation. The design of the traditional cooking stove and the type of fuel used are important determinants of fuel use efficiency, which is related to the emission of greenhouse gases [5].

The construction of the traditional cooking stove leads to combustion processes inside stoves to be non-ideal, thus,

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favoring incomplete combustion. Due to the incomplete and inefficient combustion, such stoves produce significant quantities of 'products of incomplete combustion' (PIC) importantly fine and ultra fine particles which have more global warming potential (GWP) than CO_2 [3]. Bhattacharya et al. [6] report that incomplete combustion of biomass in the traditional cooking stove release carbon monoxide (CO), nitrous oxide (N_2O), methane (CH_4), polycyclic aromatic hydrocarbons (PAHs), particles composed of elemental carbon or black carbon, and other organic compounds. The importance of PIC has been a focus of the globally concern society not only for its GWP but also for the detrimental effects to the human health. The release of CO from the traditional stove has been identified in such level that can be potentially poisonous to human. Other PICs such as N_2O, nonmethane hydrocarbon (NMHC) and PAHs are also very dangerous to human health [4].

The article 12 of the Kyoto Protocol introduces the clean development mechanism (CDM) which helps attain GHG reduction commitment of the Annex I countries and derive sustainable development in the host (Non-Annex I) countries. Silveira [7] concludes that bioenergy projects are attractive and CDM provides a complimentary bridge for international cooperation towards sustainable development. Ravindranath et al. [8] and Reddy and Balachandra [9] also conclude that a wood fuel stove project with the improvement of the traditional cooking stove can well be put on the international 'carbon market' at competitive cost for GHG reduction.

Understanding wood fuel consumed by the traditional cooking stoves, its structural dimension and its consequences, can be policy tools of the energy and global warming mitigation policy makers to restructure the cooking stove system, mitigate the global warming and to reduce the health hazards in Bangladesh. Jashimuddin et al. [10] find out the preference and consumption pattern of biomass fuel in some disregarded villages of Bangladesh. Miah et al. [11] report the biomass fuel use by rural households in the Chittagong region of Bangladesh. Ali [12] reports that research and development in the Bangladesh energy sector are very limited, with the rural energy sector being severely neglected. No recommendation has been made on the choice of energy technology particularly for rural Bangladesh. No research work was so far been carried out on the wood fuel use in the traditional cooking stoves and its consequences in Bangladesh. Thus the present study was undertaken to determine the wood fuel use in the traditional cooking stove, its structural dimension in the rural floodplain areas of Bangladesh. The study also figured out the health hazards due to the incomplete combustion of biomass and contribution to global warming; and its improvement to fit with the CDM; based on the extensive literature review.

2. Methodology

2.1. Study area

The study was conducted in the rural Begumganj Upazila (sub-district) of Noakhali District (Fig. 1). Noakhali, the deltaic District in Bangladesh, is situated at the edge of the Bay of Bengal. Begumganj Upazila has 26 Unions, 325 Mauzas and 347 Villages [1]. In Bangladesh, an Upazila is composed of some Unions, composed of some Mauzas which are composed of some Villages. In the present local government system of Bangladesh, Upazila and Union are regarded as important local government strata and social institutions. Mauza and Village have no local government body. Each stratum is different with its area in descending order. The estimated number of households in the Upazila in 2001 was 133,945 and the population was 767,170, which constituted

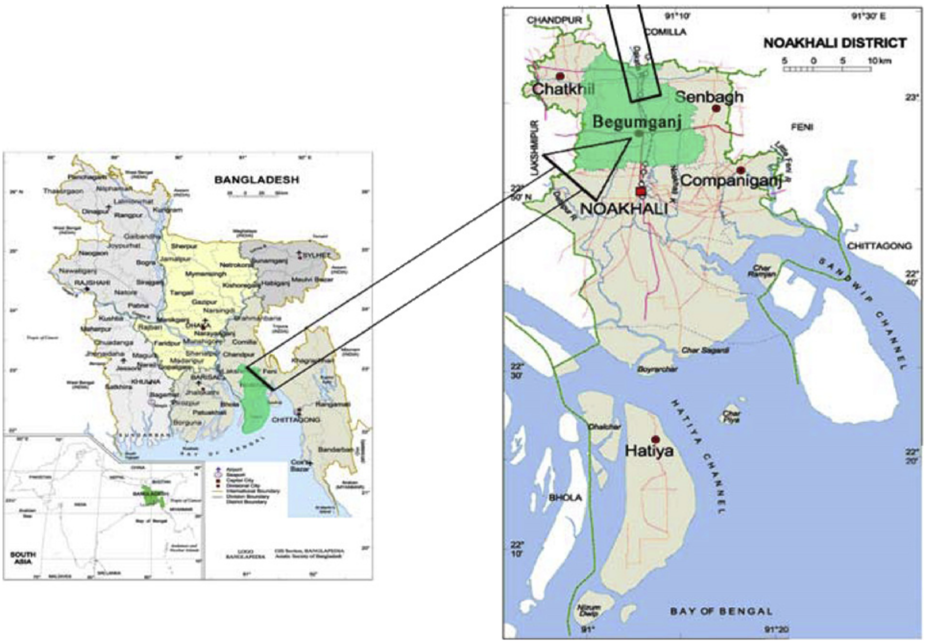

Fig. 1 – Map of Bangladesh showing Begumganj Upazila (particular study site).

about 0.59% of the total population of the country [13]. The population density was 1800 per km^2 compared to 843 per km^2 for the country as a whole. The rate of literacy was 55.4% compared to 37.7% for the nation [13]. The climate of the Upazila is moderated by the proximity to the Bay of Bengal. The annual temperature varies from 14.6 to 33 °C. The level of humidity is generally around 77% in January and around 90% in July. Annual rainfall in 1996 was 2872 mm, occurring mainly from June to October [14]. The offshore islands and the immediate coastal areas of the Upazila are frequently affected by cyclonic storms and tidal surges. Except for the government-sponsored afforestation program for the coastal belt, there is no organized tree planting in the district. However, homestead lands are usually covered by dense and lush green foliage from a wide variety of trees. Homestead is a last and the smallest operational unit in the country composed of a piece of land housing the residence of the family and a little space. Homestead forests in Bangladesh were being considered as a sustainable production system since the time immemorial. The major functions of the homestead forests especially in the rural areas are subsistence production and income generation. It encounters a traditional agroforestry system where trees are the important component [11]. Because of the high biodiversity existing in the homestead, a wide spectrum of multiple-use products can be generated with relatively low labor, cash or other inputs. They also fulfill many social, cultural and ecological functions. The multilayered vegetation structure of the homestead forests contributes substantially to this production system. Among others, this structure protect the soil from erosion, offers a habitat to wild plants and animals, promotes a favorable microclimate, and makes efficient system of light, water and other resources. Presently, this type of forest production system is being threatened by the socio-economic factors increasingly losing their sustainability. This type of forestry production system is totally different from the natural forests or commercial plantation. Mostly, the government and highly rich private owners own the natural forests and commercial plantations, respectively, which are non-existent in the study area.

2.2. *Methods*

The study was conducted from February to May, 2003. Before starting the exact data collection, a reconnaissance survey was carried out to understand the family size-class, number of households in a village, cooking stove pattern and other variables mentioned in this study. It contributed to construct the questionnaires and number of samples. A total of 60 households were selected from the Upazila using a stratified random sampling procedure. The sequence of selection was from Upazila to Union, from Union to Village and then to households with different family size classes: very small (3–4), small (5–6), medium (7–8), large (9–10) and very large (11–12). Out of 26 Unions of Begumganj Upazila, 4 Unions were selected randomly: Alyerapur, Bazra, Begumgonj and Eklashpur. From each Union, one village was selected randomly: Doalia Bazar from Alyerapur, Bazra from Bazra, Mahabbatpur from Begumgonj and East Eklashpur from Eklashpur Union. From each village, 15 households were selected randomly. It was found that a village had 100–125 numbers of households. So, 15 household samples in a selected village were considered enough. For selecting the Union, village and household, randomization was strictly maintained to avoid the biasness.

Patterns of consumption of biomass fuel and non-biomass fuel were studied using a semi-structured questionnaire. Data and information on stove design, raw material used in making the cooking stove, sources and quantity of wood fuel, socio-economic information and problems incurred from using biomass in the traditional cooking stoves were collected by interviewing the principal cook in each selected household. The data on quantity of wood fuel used were collected in local units, such as cartloads, *auri*, maund and headloads. These units except maund were very much localized. One maund is equivalent to 37 kg. Other units varied from Union to Union. The ranges of units were as cartload 700–1000 kg, *auri* 25–35 kg and headload 20–25 kg. To make sure of the localized weight measuring units, at every union one average value was undertaken for each unit by verifying the measuring units through physical experimentation in the reconnaissance survey. The localized units of weight were then converted into 'tonne dry matter' (tdm). The primary data on wood consumption recorded in daily basis, were converted to annual consumption. The fuel wood was observed to be airdried at ovendry condition before burning. To be confirmed about the moisture content of the woody biomass used, moisture content of fuel wood of every species collected from the study households was tested in the laboratory of Institute of Forestry and Environmental Sciences, Chittagong University, Bangladesh. The moisture content of wood to be used by the cooking stove was found with the range 20–25%. So, the fuel wood used was considered as drymatter. The consumption of biomass fuel was recorded over a period of 24 h of each day. The data were collected everyday of the first week of the first month, the second week of the second month, the third week of the third month and the fourth week of the fourth month for each household. In Bangladesh, usually foods are cooked three times a day at the household level. In the study it was confirmed that the range of the cooking times was 6:00 a.m. to 9 p.m. In each household, one randomly selected day was designated to conduct direct measurement of the fuel wood used. But the physical verification and reporting by the cookers was not found significantly different at both 0.05 and 0.01 levels. The means of the woodfuel consumed (tonne family^{-1} year^{-1}) measured physically was 4.28 with standard deviation, 1.62. The sample size was 60. A *t*-test was carried out to compare the direct measurement of woodfuel with the reporting of the cookers.

After collecting all the data, the households were subdivided into five family size classes for calculation, i.e., very small, small, medium, large and very large with the number of samples, 8 (13%), 18 (30%), 21 (35%), 9 (15%) and 4 (7%), respectively. While collecting data from the households, cares were undertaken so that samples represent the different family sizes. In the traditional cooking stove, sun-dried wood fuels are used in which moisture content is assumed to be at that level that optimizes burning and were also used for estimating the carbon contents and greenhouse gas emission.

The consumption of biomass measured in local units (head loads, cartloads and mound) during the field survey was converted into units of mass (tdm) to standardize the data. The primary data on wood consumption, which were recorded on daily basis, were converted to annual consumption. The PIC emitted from the traditional cooking stove and its effects on human health and global warming has been reviewed from the extensive literatures. But, while recording the health hazards related to using the traditional cooking stoves, illness were not medically diagnosed. The first two authors with other paid crews directly conducted the interview in the field. The third author was involved in planning and finalizing the research output. The respondents of the study were the main cookers and the household dominators. To reduce the biasness in selecting the respondents, a participatory discussion was followed. In the study area, all the cooks were found women. In 30% households, multiple cookers were found. In that case only leading cooker was selected as principal respondents. However, women spouse, grandmother, elderly sister were found as the cooker in the households. All of the multiple cookers were found in the extended families and single cooker in the nuclear family. A 43% nuclear families and 57% extended families were found for this study where 70% women spouse, 20% grand mother and 10% elderly sisters were the main cookers. In the rural floodplain areas, the head of household is usually male and they usually collect the fuel wood, chip the fuel wood for air drying. All of the heads of household of the study were found male. Accordingly, the male was asked about the fuel wood collection, species use, quantity and so on. The cooker was asked about the construction of the cooking stove and health effects due to the fuel wood burning. Data collected from all of the respondents were crosschecked with the physical experimentation and discussion with the other family members. To show the variability among the cooking stove dimensions, one-way ANOVA test was carried out for the homogenous varianced variables and Kruskal–Wallis test for the heterogeneous varianced variables. SPSS 13.0 for Windows was used for those tests.

2.2.1. *Estimation of the collection of fuel wood from the homestead forests*

Deforestation was measured in units of cubic meters (m^3) of the commercial (woody) portion of biomass. The basic source of all of the fuel wood burnt in the rural cooking stove in the study area was the homestead forest. Even though homestead forestry production system was regarded as the sustainable wood production system in the rural Bangladesh, presently it is unsustainable due to the fragmentation of the household lands and rapid increase of the population. In addition to this, due to the widespread destruction of the national forests, a huge pressure on the forest products has been imposed in the homestead forests which are making the homestead forests unsustainable and thereby leading to the deforestation [2,10,11]. The data of mass units (tdm) were converted into cubic meter (m^3) per unit of time. Conversion to cubic meters was accomplished by dividing the mass units by the density of wood of the relevant species [15].

3. Results and discussion

3.1. *Dimensions and characteristics of cooking stoves*

Three types of cooking stoves were found in the study area: single mouth, double mouth and triple mouth (Fig. 2). The type used depended on the amount of cooked items. Clay, sand, cow dung, rice husks and sawdust were mainly used to construct those types of stoves.

It was found that the greatest average diameter of the mouth or pot-hole (23 cm) was in the triple mouth because those hold big pots in cooking. Single and double mouth stoves both had the same diameter (22 cm). The average diameter of the feeding hole was greatest (21 cm) in the triple mouth compared to the single (18 cm) and double mouth stove (20 cm). Average height of cones of a mouth was the same in all types of stoves. The triple mouth stove had the greatest cost (4.2 US$), followed by double mouth (3.4 US$) and single mouth (2 US$) (Table 1).

Average depth (52 cm), width (50 cm) and length (65 cm each arm) were also greatest in the triple mouth stove compared to the other two. Width was almost same (35 cm) in the single and double mouth stove. In most cases, it was found that no direct cost was involved in making those types of stoves, because all the materials were easily found locally without cost and the rural women of the households made the stoves without any direct labor cost.

Hossain [16] describes how the traditional stove allows excessive loss of heat. The large distance between the pot and fuel bed causes heat transfer to cooking pot to be considerably reduced. Because of the large size of flue gas exits between the cooking pot and stove, much of the hot flue gas exits the stove without coming into contact with the cooking pot, thus reducing the convective heat transfer. Since air cannot reach the bottom of the stove, a considerable amount of cooking fuel accumulates at the bottom as charcoal. The dimensions of the cooking stoves in the study area indicate the inefficiency of biomass burning. Akter and Hossain [17] also found the heat utilizing inefficiency in the biomass burning traditional cooking stove in Bangladesh.

3.2. *Income of the household, wood fuel consumption, burning time and their estimated market value*

Average burning time among the 60 households was 3.55 $h\,day^{-1}\,family^{-1}$ with maximum 4.5 $h\,day^{-1}\,family^{-1}$ in the very large families and minimum 2.17 $h\,day^{-1}\,family^{-1}$ in the very small families, respectively (Table 2). The study showed that the average wood consumed for household cooking was 4.24 tonnes or 6.52 $m^3\,family^{-1}\,year^{-1}$. For that consumption, each family spent on an average 175 US$ $year^{-1}$ (Table 2).

It was clear that large families consumed more wood fuel and spent more money than smaller families. Household consumption of fuel wood was positively correlated with family size ($r = 0.79$).

Raw materials except labor utilized for making traditional cooking stoves, are presently readily available in the rural

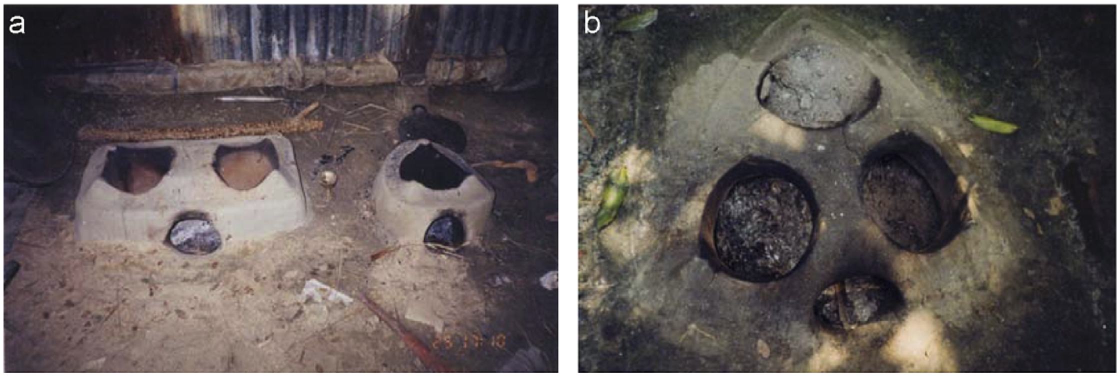

Fig. 2 – (a) A double and single mouth and (b) a triple mouth cooking stove in the rural floodplain areas of Bangladesh.

Table 1 – Cooking stove dimensions and characteristics in the rural floodplain areas of Bangladesh

Type of stove	Diameter of mouth/pot hole* (cm)	Diameter of feeding hole* (cm)	Height of cones in a mouth (cm)	Depth** (cm)	Width** (cm)	Length** (cm)	Cost** US$
Single mouth	22^{a} (0.63)$^{\#}$	18^{a} (0.40)	5^{a} (0.20)	45^{a} (0.86)	35^{a} (0.65)	36^{a} (0.64)	2^{a} (0.11)
Double mouth	22^{a} (0.70)	20^{b} (0.66)	5^{a} (0.24)	47^{ab} (0.62)	35^{ab} (0.64)	63^{b} (1.23)	3.4^{b} (0.23)
Triple mouth	23^{b} (0.27)	21^{bc} (0.97)	5^{a} (0.25)	52^{c} (1.13)	50^{c} (1.06)	65^{bc} (0.81) (eacharm)	4.2^{c} (0.16)

$^{\#}$Figure in the parentheses indicates the standard error.

*Significance level at 0.05 and **significance level at both 0.05 and 0.01 levels among the three different cooking stoves.

The letters a, b and c are used to show the significance difference ($P = 0.05$) between/among the values within a column according to the Contrast test in the one-way ANOVA. Values in the same column followed by the same letters are not significantly different.

Table 2 – Average monthly income, burning time, consumption of wood fuel and its estimated market value in the rural floodplain areas of Bangladesh

Family size	Number of families	Income level (US$)	Burning time (h day^{-1} family^{-1})	Average income (US$)	Estimated wood fuel consumed (tonne family^{-1} year^{-1})	Estimated market value of annual consumption of wood fuel (US$)
Very small	8	42–85	2.17	59 (13.95)^{a}	2.94 (4.52)^{b}	121
Small	18	34–119	3.2	78 (18.78)	3.69 (5.68)	152
Medium	21	51–169	3.78	88 (22.58)	4.31 (6.63)	178
Large	9	102–153	4.1	125 (17.45)	5.09 (7.83)	210
Very large	4	85–203	4.5	136 (49.38)	5.16 (7.94)	213
Average			3.55		4.24 (6.52)	175

^{a} Figure in the parentheses indicates standard deviation.

^{b} Figure in the parentheses indicates collection of woody biomass from the homestead forests in m^3 family^{-1} year^{-1}.

floodplain areas of Bangladesh. The cookstove makers just need to collect these materials from their surroundings. The whole procedure needs the three steps, i.e., collection of the raw materials, building the cooking stove and air-drying it in the sun. In the whole production system of this cooking stove, labor cost is important. The unpaid labor of the stove construction which is usually by the cook, was monetized at the local manual labor rate at \$1.2 day^{-1} person^{-1}.

3.3. *Sources of fuel wood and use of species*

The main sources of fuel wood were own homestead and market because there was no natural forest or commercial plantation for energy or timber in the vicinity. It was found that 40% of families in the study area collected wood fuels only from their own homesteads and 13% only from the market, 47% were dependent on both market and own homestead.

Only 5% of families used liquefied petroleum gas (LPG) along with biomass fuel, and 42% used only biomass fuel in their cooking, where other alternative fuel was not available. Also 53% of the families were dependent on kerosene in addition to biomass fuel. The study showed that all households used Mandar (*Erythrina indica*) followed by Mangiam (*Acacia mangium*) 83%, Koroi (*Albizia* spp.) 75%, Eucalypts (*Eucalyptus camaldulensis*) 70%, Jam (*Syzygium grande*) 57%, Kanthal (*Artocarpus heterophyllus*) 52% and Aam (*Mangifera indica*) 48% (Table 3).

Generally, the tree species used in cooking stoves in the floodplain area in this study are similar to other floodplain samples in Bangladesh. Miah and Hossain [18] found more or less the same tree species composition in the Narsingdi floodplain areas of Bangladesh. Our study found *E. indica* to be used by all the households as fuel, but Miah and Hossain [18] found *Trewia nudiflora* as the major fuel wood species. But both of these species are native to the moisture-rich lands as recorded by Prain [19]. The tree species used for fuel wood may vary in different agro-ecological zones in Bangladesh, but the tendency has been shown for the sources of collection to be the same as in the hilly areas of Bangladesh. Miah et al. [11] found that among the various sources used by households for collecting fuel wood, homestead forests were the most important (33%) followed by markets (28%), secondary forests/plantations (25%) and agricultural residues (15%). This shows the same trend for sources of fuel wood in all ecological zones in Bangladesh differing with secondary forests/plantations. It was found that the income of the family influenced the alternative fuels to be used.

Shanavas and Kumar [20] experimented the specific gravity, green moisture content, ash content and heat of combustion of *E. indica* as 0.254, 57%, 7% and 15.20 $\mathrm{kJ\,g^{-1}}$ dry weight, respectively. They also found that ash content had a negative correlation with heat of combustion. The results of this species also were compared with other fuel wood species which showed a comparative lower burning capacity due to the ash contents. The more ash content in this species proves the report of the households of producing more smokes while burning.

3.4. *Socio-economic and environmental effects of incomplete combustion of the traditional cooking stove*

3.4.1. *Deforestation effects of the fuel wood use in the traditional cooking stove*

Due to the inefficient use of wood fuel throughout the country, widespread destruction of forests including homestead forests has reduced the forest cover to about 8% from the minimum requirement of 25% of the land area of the country [21]. Collection of fuel wood for use in the traditional cooking stove is not the sole cause of deforestation in homestead forests in Bangladesh. As the national forests in Bangladesh have been significantly degraded, they are no longer able to supply the needs of the people of the country for forest products. So, for timber, bamboo and other non-timber forest products, the people are mostly dependent on homestead forests, which have implications for the recent deforestation in rural areas. But in terms of greenhouse emissions, using traditional cooking stoves has some serious implications. It is already proven fact that traditional cooking stoves in the rural Bangladesh are low efficient due to the incomplete combustion of the fuel wood [16,17]. This low efficiency is resulting high consumption of fuel wood which is leading to the more collection of fuel wood from the forests. Furthermore, plantations in rural areas are not sustainable and so are not able to contribute to net carbon sequestration. Streets and Waldhoff [4] report the deforestation due to the unsustainable harvesting of woody biomass mentioning ‘while some countries are working toward sustainable harvesting, it is not the common practice in most of the developing world, and many upland areas of Asia have been severely degraded by unsustainable harvesting of fuel wood’. Smith et al. [3] also confirm that ‘even if renewably harvested, biomass fuel cycles are often not GHG neutral because of their substantial production of PIC’.

3.4.2. *Health effects of the biomass burning traditional cooking stoves*

In the study, all women had irritated eyes while engaged in cooking with these traditional stoves. Also, 70%, 68%, 83% and 63% of women had headaches, lung diseases, asthma and cardiovascular diseases, respectively. The household reported that large amount of smoke emitted from their cooking stoves was harmful to women and children of the area. As the health

Table 3 – Major tree species used as fuel in the rural floodplain area in Bangladesh

Local name	Scientific name	Number of families using species	Percentage of families
Mandar	*Erythrina indica*	60	100
Mangiam	*Acacia mangium*	50	83
Koroi	*Albizia* spp.	45	75
Eucalyptus	*Eucalyptus camaldulensis*	42	70
Jam	*Syzygium grande*	34	57
Kanthal	*Artocarpus heterophyllus*	31	52
Aam	*Mangifera indica*	29	48

effects of the biomass burning in the traditional cooking stoves in the study area was not medically diagnosed and even there was no such study for Bangladesh available, so the results of this kind of health effects reported in different developing countries have been summarized here through an extensive literature review.

The effects of PICs on human health have been reported by many scientists in the world. Among them acute respiratory infections; asthma; blindness; cancer; chronic obstructive pulmonary disease; eye discomfort, headache, back pain; reduced birth weight; stillbirth; and tuberculosis, have been reported for Kenya, India, Nepal, Papua New Guinea, Guatemala, Turkey and Zimbabwe, damaging specially to women and children's health (Table 4). As the combustion of biomass depends on the type of biomass and device of the cooking stoves; and the exposures to the PICs depends on the architectures' of the kitchen, so the health effects cannot be exactly same in all countries. As the socio-economic conditions and technological access situation of the rural areas of Bangladesh and India is almost same, so it can be guessed that biomass burning effects to the health are same between Bangladesh and India.

3.4.3. *Global warming effects of traditional cooking stoves and CDM implications*

The PICs emitted from the cooking stove share the larger portion of energy-related emissions in terms of total GWP (in CO_2 equivalents) comprising 38% over a 20 years time frame and 31% over a 100 years time frame [4]. Even if this is assumed to be consumed over a sustainable basis, it accounts for 4.5% of the total carbon emissions and 23% of CO_2 equivalents on 20 years GWP basis. IPCC [32] describes that the direct GWP (mass basis) of CH_4 for 20, 100 and 500 years are 62, 23 and 7, respectively; and N_2O are 275, 296 and 156, respectively, for the same time horizons with the reference to CO_2. So, based on the carbon-weight, these PICs contribute to global warming far more than CO_2. In Bangladesh, there is a need to develop fuel-efficient wood-burning stoves so as to improve health and hygiene, reduce drudgery of women, reducing fuel consumption, and improve forest protection and the environment. In the present study, 83% of women said they would like improved cookstoves because of the smoke-related health problems. However, 17% were not willing to consider improved cooking stoves because of the money constraints.

Gowda et al. [33] showed that if an improved cooking stove replaced the traditional mud-built cooking stove, each family unit could reduce its annual fuel wood consumption by about two-thirds in the rural areas of South India. Rubab and Kandpal [34] provided some typical numerical calculations revealing that the replacement of the traditional cookstove by an improved one is financially quite attractive. Smith et al. [35] described how the Chinese national improved stove program introduced some 129 million improved stoves into rural areas during 1982–1992, mostly biomass cookstoves, but also including coal and space heating stoves in some areas. Although there were problems with quality control and durability, particularly at the beginning of the program, more than two-thirds of those stoves seemed to be in use during that period. Although GHG emission and health hazards from the traditional cooking stoves were not much concern in the last decades, but the growing scarcity of biofuels, which was partly due to their inefficient utilization in traditional cooking stoves, had been the primary motivating factor for the development and dissemination of improved biofuel cooking stoves [34,36]. Bhattacharya and Salam [37] report that new stove designs can improve the efficiency of biomass use for cooking by a factor of 2–3; and save the amount of biomass through increase in biomass use efficiency. It can reduce GHG emission further through substitution of fossil fuels. Bhattacharya et al. [38] studied the 'potential of biomass fuel conservation in selected Asian countries' including China, India, Nepal, Pakistan, Philippines, Sri Lanka and Vietnam. They estimated that through the efficiency improvements in these countries, total biomass fuels saved to be 326 million tonnes $year^{-1}$. In total, the improved ones can save around 152 million tonnes of fuel wood in the domestic sector which is about 43% of the total fuel wood use in the domestic sector. In Bangladesh, a severe dependence on biofuels by a large number of populations can demand a substantial potential for diffusion of improved cooking stoves; which can save the fuel wood thereby slowing the deforestation and minimize the GHG emission.

Table 4 – Health effect due to the incomplete combustion of biomass in the biomass burning traditional cooking stove in different developing countries

Health effects	Main victim	Country	Reference
Acute lower respiratory infections	Children	Kenya, India, Nepal, Papua New Guinea	[22]
Acute respiratory infections	Children	India	[23]
Asthma	Children	Guatemala	[24]
Blindness	Men and women	India	[25]
Cancer	Women	India	[26]
Chronic obstructive pulmonary disease	Women	Turkey	[27]
Eye discomfort, headache, back pain	Women	Guatemala	[28]
Reduced birth weight	Women	Zimbabwe	[29]
Stillbirth	Women	India	[30]
Tuberculosis	Men and women	India	[31]

4. Conclusions and recommendations

Biomass fuel use per family per day largely depends on the family size, family income, amount cooked and burning time. The emission of PIC depends on the consumption of biomass fuel. Three types of traditional cookstoves, single, double and triple mouth, were used in the floodplain rural area of Bangladesh, but those stoves had only one feeding hole and the depth, width and length of those stoves were not suitable for efficient cooking. Traditional cooking stoves also threaten the health of women working in the kitchen. Mander (*E. indica*) was used by all the families in the study area. However, the combustion efficiency of Mander is less than that of other species like Koroi (*Albizia* spp.) and Mangium (*Acacia* spp.), and also creates lot of smoke. Almost all women would prefer improved cooking stove, even if costly, because they understood the problems of traditional stove and the prospects of improved cooking. The extensive literature review shows that indoor air pollution from household cooking apparently results to substantial health damages especially in the developing countries and GHG emission as PIC. The following recommendations are made to effectively target the interventions in Bangladesh.

(1) Improved cooking stoves should be introduced throughout the rural area of Bangladesh with minimum cost so that they are easily accessible to the rural poor. The Government and NGO efforts should be strengthened to disseminate this technology.
(2) Plantations of fast-growing fuel wood species like *Acacia* spp., *Albizia* spp., etc. should be expanded in the gaps of village groves.
(3) Alternative renewable energy sources may be accessible to rural women, which may reduce the dependency on wood. These may include solar energy and bio-gas, for which low-cost efficient cookers should be introduced in the rural areas.
(4) The national program to subsidize the cost of improved cooking stoves should be expanded. Government or non-government organizations may launch a new marketing system to introduce improved cooking stoves to rural areas.
(5) To include the improved cooking stoves in CDM projects, baselines, additionality, leakage, monitoring, and accounting procedures, project requirements, vis-à-vis all of the above areas, must be standardized, straightforward and easy to apply to avoid excessive transactions costs.
(6) Standard rules and procedures, for defining and quantifying carbon credits at the project level, must be developed to feasibly generate 'biomass combustion efficiency in the cooking stove' under the CDM.
(7) Better understanding on the epidemiology and exposure assessment can lead to better interventions to reduce the health effects and GHG emissions. 'Tuberculosis and cardiovascular disease under case–control studies in women and randomized intervention trials acute respiratory diseases in the childhood and adverse pregnancy outcomes' can be useful for epidemiological implications of the incomplete combustion of biomass in the traditional cooking stove. Inexpensive exposure assessment techniques and low-cost equipment at large scale, including national level surveys', can help identify the exposures. The PIC from different woody species should be identified. 'Engineering and dissemination approaches for improved stoves, fuels, ventilation, and behavior that reliably and economically reduce exposure' should be studied.

However, this study is expected to help the policy makers to formulate rural energy planning in Bangladesh.

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